

# The Dark Energy Paradigm

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## Abstract

Though the concept of a dark energy driven accelerating universe was introduced by the author in 1997, to date dark energy itself, as described below has remained a paradigm. A model for the cosmological constant is suggested.

## 1 Introduction

The author in 1997 proposed a dark energy driven accelerating universe with a small cosmological constant. In 1998, the observations of Perlmutter and others on distant type Ia supernovae confirmed the above scenario - this work was infact the Breakthrough of the Year 1998 of the American Association for Advancement of Science's Science Magazine [1, 2, 3]. Subsequently observations by the Wilkinson Microwave Anisotropy Probe (WMAP) and the Sloan Digital Sky Survey confirmed the predominance of the new paradigmatic dark energy - this was the Breakthrough of the Year 2003 [4]. Such a background energy with negative pressure (to cause repulsion) is now called Dark Energy. Moreover the so called Large Number coincidences including the mysterious Weinberg formula are deduced in the author's theory, rather than being miraculous coincidences. We examine the concept of dark energy in this context and indicate how this energy may even be harnessed. We first observe that the concept of a Zero Point Field (ZPF) or Quantum Vacuum (or Vacuum energy) is an idea whose origin can be traced back to Max Planck himself. Quantum Field Theory attributes the ZPF to the virtual Quantum effects of an already present electromagnetic field [5].

In a very intuitive way Faraday could conceive of magnetic effects in vacuum in connection with his experiments on induction. Based on this, an aether was used for the propagation of electromagnetic waves in Maxwell's Theory of electromagnetism, which in fact laid the stage for Special Relativity. This aether was a homogenous, invariable, non-intrusive, material medium which could be used as an absolute frame of reference, at least for certain chosen observers. However the experiments of Michelson and Morley towards the end of the nineteenth century, led to its downfall, and thus was born Einstein's Special Theory of Relativity in which there is no such absolute frame of reference.

Very shortly thereafter the advent of Quantum Mechanics led to its rebirth in a new and unexpected avatar [6]. Essentially there were two new ingredients in what is today called the Quantum Vacuum. The first was a realization that Classical Physics had allowed an assumption to slip in unnoticed: In a source or charge free "vacuum", one solution of Maxwell's Equations of electromagnetic radiation is no doubt the zero solution. But there is also a more realistic non zero solution. That is, the electromagnetic radiation does not necessarily vanish in empty space.

The second ingredient was the mysterious prescription of Quantum Mechanics, the Heisenberg Uncertainty Principle, according to which it would be impossible to precisely assign momentum and energy on the one hand and spacetime location on the other. Clearly the location of a vacuum with no energy or momentum cannot be specified in spacetime.

This leads to what is called a Zero Point Field. For instance a Harmonic Oscillator, a swinging pendulum for example, according to classical ideas has zero energy and momentum in its lowest position. But the Heisenberg Uncertainty endows it with a fluctuating energy. This fact was recognized by Einstein himself way back in 1913 who, contrary to popular belief, retained the concept of aether though from a different perspective [7]. It also provides an understanding of the fluctuating electromagnetic field in vacuum.

This mysterious Zero Point Field or Quantum Vacuum energy has since been experimentally confirmed in effects like the Casimir effect which demonstrates a force between uncharged parallel plates separated by a charge free medium, the Lamb shift which demonstrates a minute oscillation of an electron orbiting the nucleus in an atom-as if it was being buffeted by the Zero Point Field- the anomalous Quantum Mechanical gyromagnetic ratio  $g = 2$  and so on [8]-[9, 10].

The Quantum Vacuum is a violent medium in which charged particles like

electrons and positrons are constantly being created and destroyed, almost instantly, within the limits permitted by the Heisenberg Uncertainty Principle for the violation of energy conservation. There are also claims that the virtual photons of the Quantum Vacuum have been realized as real photons, in an endorsement of the dynamical Casimir effect (Cf.ref.[11]). One might call the Quantum Vacuum as a new state of matter, a compromise between something and nothingness. Something which corresponds to what the Rig Veda described thousands of years ago: "Neither existence, nor non existence."

The Quantum Vacuum can be considered to be the lowest state of any Quantum field, having zero momentum and zero energy. The properties of the Quantum Vacuum can under certain conditions be altered, which was not the case with the erstwhile aether. In modern Particle Physics, the Quantum Vacuum is responsible for phenomena like Quark confinement, a property whereby it would be impossible to observe an independent or free Quark, the spontaneous breaking of symmetry of the electroweak theory, vacuum polarization wherein charges like electrons are surrounded by a cloud of other oppositely charged particles tending to mask the main charge and so on. There could be regions of vacuum fluctuations comparable to the domain structures of ferromagnets. In a ferromagnet, all elementary electron-magnets are aligned with their spins in a certain direction. However there could be special regions wherein the spins are aligned differently.

Such a Quantum Vacuum can be a source of cosmic repulsion, as pointed by Zeldovich and others [12, 13]. However a difficulty in this approach has been that the value of the cosmological constant turns out to be huge, far beyond what is observed. This has been called the cosmological constant problem [14]. If true, the universe would have exploded into nothing, shortly after its birth.

There is another approach, sometimes called Stochastic Electrodynamics which treats the ZPF as primary and attributes to it Quantum Mechanical effects [15, 16]. It may be re-emphasized that the ZPF results in the well known experimentally verified Casimir effect [17, 18].

We would first like to observe that the energy of the fluctuations in the background electromagnetic field could lead to the formation of elementary particles. Indeed this was Einstein's belief. As he observed as early as 1920 itself [19], "... according to our present conceptions, the elementary particles are... but condensations of the electromagnetic field."

In the words of Wilzeck, [20], "Einstein was not satisfied with the dualism.

He wanted to regard the fields, or ethers, as primary. In his later work, he tried to find a unified field theory, in which electrons (and of course protons, and all other particles) would emerge as solutions in which energy was especially concentrated, perhaps as singularities. But his efforts in this direction did not lead to any tangible success.”

## 2 The Quantum Vacuum

Let us consider, following Wheeler [10] a harmonic oscillator in its ground state. The probability amplitude is

$$\phi(x) = \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} e^{-(m\omega/2\hbar)x^2}$$

for displacement by the distance from its position of classical equilibrium. So the oscillator fluctuates over an interval

$$\Delta x \sim (\hbar/m\omega)^{1/2}$$

The electromagnetic field - or for that matter, any collection of bosons - is an infinite collection of independent oscillators, with amplitudes  $X_1, X_2$  etc. The probability for the various oscillators to have amplitudes  $X_1, X_2$  and so on is the product of individual oscillator amplitudes:

$$\phi(X_1, X_2, \dots) = \exp \left[ - \left( X_1^2 + X_2^2 + \dots \right) \right]$$

wherein there would be a suitable normalization factor. This expression gives the probability amplitude  $\phi$  for a configuration  $B(x, y, z)$  of the magnetic field that is described by the Fourier coefficients  $X_1, X_2, \dots$  or directly in terms of the magnetic field configuration itself we have

$$\phi(B(x, y, z)) = P \exp \left( - \int \int \frac{B(x_1) \cdot B(x_2)}{16\pi^3 \hbar c r_{12}^2} \right)$$

$P$  being a normalization factor. Let us consider a configuration where the magnetic field is everywhere zero except in a region of dimension  $l$ , where it is of the order of  $\sim \Delta B$ . The probability amplitude for this configuration would be proportional to

$$\exp[-(\Delta B)^2 l^4 / \hbar c]$$

So the energy of fluctuation in a region of length  $l$  is given by finally [10, 21, 22]

$$B^2 \sim \frac{\hbar c}{l^4} \quad (1)$$

We next argue that  $l$ , the mean length of fluctuations, will be the Compton length. We note that as is well known, a background ZPF of the kind we have been considering can explain the Quantum Mechanical spin half as also the anomalous  $g = 2$  factor for an otherwise purely classical electron [23, 24, 25]. The key point here is (Cf.ref. [23]) that the classical angular momentum  $\vec{r} \times m\vec{v}$  does not satisfy the Quantum Mechanical commutation rule for the angular momentum  $\vec{J}$ . However when we introduce the background Zero Point Field, the momentum now becomes

$$\vec{J} = \vec{r} \times m = \vec{v} + (e/2c)\vec{r} \times (\vec{B} \times \vec{r} + (e/c)\vec{r} \times \vec{A}^0), \quad (2)$$

where  $\vec{A}^0$  is the vector potential associated with the ZPF— for example if the electric part of the ZPF is  $\vec{E}^0$ , this is usually considered to be a Gaussian random process and  $\vec{A}^0$  is related to  $\vec{E}^0$  by the usual Maxwell equation.  $\vec{B}$  is an external magnetic field introduced merely for convenience, and which can be made vanishingly small.

It can be shown that  $\vec{J}$  in (2) satisfies the Quantum Mechanical commutation relation for  $\vec{J} \times \vec{J}$ . At the same time we can deduce from (2)

$$\langle J_z \rangle = \frac{1}{2} \hbar \omega_0 / |\omega_0| \quad (3)$$

Relation (3) gives the correct Quantum Mechanical results referred to above. From (2) we can extend the arguments and also deduce that

$$l = \langle r^2 \rangle^{\frac{1}{2}} = \left( \frac{\hbar}{mc} \right) \quad (4)$$

(4) shows that the mean dimension of the region in which the fluctuation contributes is of the order of the Compton wavelength of the electron. By relativistic covariance (Cf.ref.[23]), the corresponding time scale is at the Compton scale.

In (1) above if  $l$  is taken to be the Compton wavelength of a typical elementary particle, then we recover its energy  $mc^2$ , as can be easily verified. As mentioned Einstein himself had believed that the electron was a result of such condensation from the background electromagnetic field (Cf.[26, 13] for details).

### 3 Cosmology

We now very briefly indicate the cosmology referred to in the introduction (Cf.ref.[27, 28]). But before that we summarize the new cosmos that has emerged since 1997: It is essentially flat with its energy constant estimated as, around 4% ordinary matters some 25% of as yet undetected dark matter, while the rest is homogenously spread out dark energy. Returning to our model, elementary particles are created from the ZPF as above. If there are  $N$  elementary particles, then fluctuationally a nett  $\sqrt{N}$  particles are created within the Compton time  $\tau$  (see ref.[27] for details), so that

$$\frac{dN}{dt} = \frac{\sqrt{N}}{\tau} \quad (5)$$

We also use the well known facts that

$$M = Nm \quad (6)$$

and

$$R = GM/c^2 \quad (7)$$

In (6),  $M$  is the mass of the Universe,  $m$  the mass of a typical elementary particle like the pion,  $N \sim 10^{80}$  the number of elementary particles in the Universe and  $R$  its radius. Differentiation of (7) and use of (6) and (5) then leads to a host of consistent relations,

$$v = \dot{R} = HR, \quad H = \frac{c}{l} \cdot \frac{1}{\sqrt{N}}, \quad (8)$$

$$G\rho_{vac} = \Lambda < 0(H^2), R = \sqrt{N}l, T = \sqrt{N}\tau, \rho_{vac} = \rho/\sqrt{N} \quad (9)$$

$$m = \left( \frac{H\hbar^2}{Gc} \right)^{1/3}, \frac{e^2}{Gm^2} \approx \frac{1}{\sqrt{N}} \quad (10)$$

and so on.

In (8) above,  $H$  is the Hubble constant,  $l$  the pion Compton length, while in (9)  $\rho$  the average density,  $\Lambda$  the cosmological constant and  $\rho_{vac}$  the vacuum density. The second relation of (9) is the empirically known so called Edington formula. The first and second relations of (10) are respectively, the Weinberg formula and the well known (but otherwise ad hoc) electromagnetism - gravitational coupling constant.

It may also be mentioned that all this can be interpreted elegantly in terms of underlying Planck oscillators in the Quantum Vacuum (Cf.refs.[29, 30]). Finally, it may be mentioned that (10) shows that both  $\Lambda$  and  $H \rightarrow 0$  as  $N \rightarrow \infty$ , as indeed is the current belief.

## 4 Harnessing the ZPF?

Two of the earliest realizations of the Vacuum energy as mentioned were in the form of the Lamb shift and the Casimir effect.

In the case of the Lamb shift, as is well known, the motion of an orbiting electron gets affected by the background ZPF. Effectively there is an additional field, over and above that of the nucleus. This additional potential, as is well known is given by [31]

$$\Delta V(\vec{r}) = \frac{1}{2} \langle (\Delta r)^2 \rangle \nabla^2 V(\vec{r})$$

The additional energy

$$\Delta E = \langle \Delta V(\vec{r}) \rangle$$

contributes to the observed Lamb shift which is  $\sim 1000mc/sec$ . The essential idea of the Casimir effect is that the interaction between the ZPF and matter leads to macroscopic consequences. For example if we consider two parallel metallic plates in a conducting box, then we should have a Casimir force given by [32]

$$F = \frac{-\pi^2 \hbar c A}{240 l^4}$$

where  $A$  is the area of the plates and  $l$  is the distance between them. More generally, the Casimir force is a result of the boundedness or deviation from a Euclidean topology in the Quantum Vacuum. These Casimir forces have been experimentally demonstrated [33, 34, 35, 36].

Let us return to equation (1). The ZPF fluctuations typically take place within the time  $\tau$ , a typical elementary particle Compton time as suggested by (4). This begs the question whether such ubiquitous fields could be tapped for terrestrial applications or otherwise. We now invoke the well known result from macroscopic physics that the current in a coil is given by

$$i = \frac{nBA}{r\Delta t} \tag{11}$$

where  $n$  is the number of turns of the coil,  $A$  is its area and  $r$  the resistance. Introducing (1) into (11) we deduce that a coil in the ZPF would have a fluctuating electric current given by

$$i = \frac{nAe}{rl^2r} \quad (12)$$

Of course, this would be a small effect. But in principle it should be possible to harness the current (12) using advanced technologies, possibly superconducting coils to minimize  $r$ .

## 5 Discussion and a Model For the Cosmological Constant

Although the concept of dark energy, is now taken for granted, its exact characterization is still a mystery. Very broadly there are two approaches. One is the cosmological constant approach we saw above. The other is to identify dark energy with a scalar field, for instance quintessence. Such a field can also be associated with a particle, fundamental or composite. Tachyonic fields have also been considered.

For example we could consider an interaction of dark energy with a fermionic field, contained in dark matter, these fermions being neutrinos [37, 38]. Attempts have been made to formulate an equation of state for a dark energy fluid [39]. Questions have also been asked whether we have dissipated cosmology or conservative cosmology as a result [40], while a generalized second law has also been studied [41]. The coincidence problem is also being studied viz., why the energy density of dark energy is roughly of the same order as a cosmological critical density [42, 43, 44].

The question may also be asked, what of dark matter, which has defied observation even after 75 years? Indeed the nature of dark matter is yet unresolved, assuming that it exists. In the author's cosmology discussed above we have a gravitational constant that depends inversely on time, as can be seen, for example from equation (10). The author has argued over the years that such a time varying gravitational constant can explain the observational anomalies which are sought to be explained by dark matter, for example the flattening of the galactic rotation curves and so on (Cf. ref. [45] and several references therein). Indeed we will show that equation (10) ultimately leads to a uniform cosmic acceleration of the rough order of  $10^{-7} cm/sec^2$ . In this



sense this approach is a substitute for the ad hoc modified Newtonian gravity approach.

In earlier communications it was shown, on the basis of the cold cosmic neutrino background, that we can consistently get the neutrino mass and other neutrino parameters [46, 47, 48]. The neutrino mass thus obtained is in agreement with the value obtained from the SuperKamiokande experiments—and in fact predicted these results [49]. One way of seeing this is to consider the cold Fermi degenerate gas [50]. We have

$$p_F^2 = \hbar^3(N/V) \quad (13)$$

Feeding in the known neutrino parameters, viz., [51]  $N \sim 10^{90}$  we get from the above, the correct neutrino mass  $\sim 10^{-3}eV$  and the background temperature  $T \sim 1^\circ K$ . More recently there has been hope that neutrinos can also exhibit the ripples of the early Big Bang and in fact, Trotta and Melchiorri claim to have done so [52].

It may be mentioned that there is growing evidence for the cosmic background neutrinos [53]. The GZK photo pion process seems to be the contributing factor.

With this background we try to extract the cosmological constant from the Fermi energy of the neutrinos background. We have

$$\text{Fermi Energy} = \frac{N^{5/3}\hbar^2}{m_\nu R^2} = M\Lambda R^2 \quad (14)$$

From (14) we get,

$$\Lambda = 10^{-37} \quad (15)$$

which gives the correct order of the cosmological constant.

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